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A. C. TRUE, Director.

THE DRAINAGE SITUATION IN THE LOWER RIO GRANDE VALLEY, TEXAS.

BY

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PREPARED UNDER THE DIRECTION OF
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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Office of Experiment Stations,
Washington, D. C., August 7, 1910.

Sir: I have the honor to transmit herewith a manuscript on the drainage situation in the Lower Rio Grande Valley, Texas, by L. L. Hidinger, of Drainage Investigations of this Office.

During the last four or five years the Lower Rio Grande Valley in Texas, especially the Brownsville section, has received a great amount of attention and the influx of investors and actual settlers has been large. The land settled and cultivated gave promise of large crops, but, as set forth in the accompanying report, after the first year or two of cultivation, the crops in many instances fell off in a marked degree. Especially was this true of the cultivation of rice, the fourth year of which saw the land abandoned on account of seepage and the rise of alkali. Even a considerable amount of land that was apparently in good condition in 1909 is now abandoned. The situation is a most serious one, and many requests have been received from those largely interested in the section urging that the results of the investigations of this Office be made available at the earliest possible moment, in order that the actual settlers may reclaim those portions of their lands already affected and prevent the injury of cultivated lands that have not yet been damaged and of new lands which they desire to put under cultivation. If something is not done at once to assist this community it will receive a most serious setback and financial loss.

Inasmuch as an immediate and intelligent handling of the situation is all that is required to reclaim these injured lands, it is desired that this report be made available for distribution at as early a date as possible. I therefore recommend that the manuscript be printed as a circular of this Office.

Respectfully,

A. C. True,
Director.

Hon. James Wilson,
Secretary of Agriculture.

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THE DRAINAGE SITUATION IN THE LOWER RIO GRANDE VALLEY.

INTRODUCTION.

The Texas side of the irrigable section of the Rio Grande Valley consists of about 450,000 acres of land lying in the shape of a wedge, with one side formed by the Rio Grande and the apex near Samfordyce, in the western part of Hidalgo County, as may be seen in figure 1. The larger part of the area is bottom land, but there is a considerable amount of land on what is known as the "second lift." The boundary of the second lift lands lies to the south of the Samfordyce branch of the St. Louis, Brownsville and Mexico Railway from Closner to a point between Donna and Mercedes, and at a distance varying from a few hundred feet to a mile from the railway. The elevation above the bottoms varies from 10 to 35 feet along the southern boundary and the slope is toward the northeast at a rate of about 2 feet to the mile. The slope of the bottoms is away from the river at about the same rate until the boundary of the second lift lands is encountered, when it slopes toward the east until near Mercedes, where the slope continues in a northeasterly direction to the Gulf of Mexico.

The better-drained parts of this valley are covered with a heavy growth of cactus and mesquite trees and the low-lying, poorly drained areas are covered with huisache bushes and salt grass. There is also a scattering growth of bunch grass, which affords some pasture for stock. Until recent years this territory was used almost exclusively for range purposes and was very thinly populated. The only means of transportation was the Rio Grande Railroad from Brownsville to Point Isabel, on the Gulf of Mexico. This railroad has a narrow gauge track that was constructed late in the seventies. Previous to that time all produce was shipped by boat down the Rio Grande to the Gulf. In 1904, however, the St. Louis, Brownsville and Mexico Railway was completed. The main line of this railway parallels the Gulf coast from Houston to Brownsville and a branch parallels the Rio Grande from Harlingen to Samfordyce (see fig. 1). Since the completion of the railway the development of the country has been wonderful. There are now about 35 land and irrigation

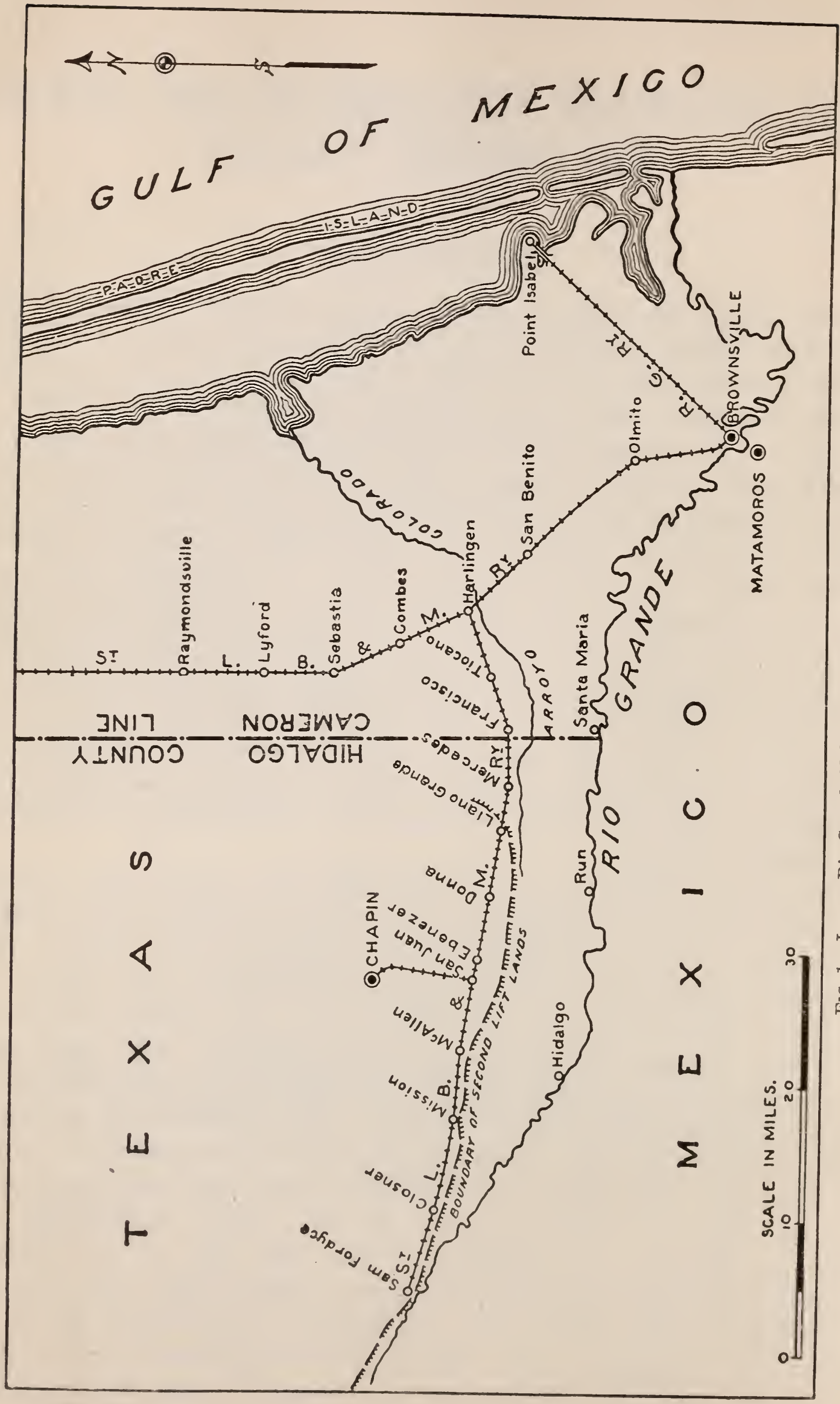

Fig. 1.—Lower Rio Grande Valley in Texas, showing irrigable section.

companies in the valley, representing an investment of several million dollars. Up to the present time (August, 1909) perhaps 100,000 acres of land have been cleared, and it is quite probable that between 40,000 and 50,000 acres will be in cultivation by the first of 1910. Settlers are constantly arriving in the valley in large numbers, and towns, sugar mills, factories, and houses are being built.

The first irrigation scheme of any magnitude was put in operation about 1902, when the Brownsville Land and Irrigation Company started to grow rice. The yield of the first crop was excellent and a bright future was predicted for the rice industry, but the second crop was not so much of a success. In the growth of rice it is necessary to keep the ground covered with water several inches in depth; and in order that it might not seep away too fast the low-lying, heavy, clay soils were chosen. These soils contain a large amount of alkali, which was rapidly concentrated at the surface by this method of culture, and it soon became evident that rice could not be profitably grown. No attempt has been made to grow rice since 1906. Since the abandonment of the rice crop, sugar cane, cotton, and truck crops have been extensively grown.

The climate of this part of Texas is classed as semitropical and semiarid, in spite of the fact that the average annual rainfall at Brownsville is 28.2 inches. All irrigation water comes from the Rio Grande. During the early summer months the river is frequently dry at El Paso, and the most of the supply for the lower part of the valley must come from the Republic of Mexico.

Assistance was first requested of this Office in 1905 and a preliminary examination was made late in that year by Mr. C. G. Elliott. The next year a representative was stationed at Brownsville for about eight months, and tests of the salt content of the soil water were made on the rice fields. From March to August, 1909, the writer was stationed at Brownsville and a careful study of the alkali problem was made throughout the valley. Several drainage systems for the reclamation of alkalied lands were designed and instructions given regarding the washing of the soil. It is the purpose of this publication to give the results of these investigations and sound a note of warning to the inexperienced and careless irrigator. A large percentage of the land upon which rice was grown contains so much alkali that crops can not be profitably cultivated, and there are seeped and alkalied spots along nearly all of the oldest irrigation canals, especially where they were constructed across the light soils. Most of the canals have been carrying water but a year or two and what water has seeped from them has gone to fill the lower subsoils. But in some instances, where the depth to water was not too great, where an impervious stratum was encountered, or where the loss was excessive, seep spots have begun to appear along the newer canals.

Where resacas have been used for storage purposes for several years, seepage almost invariably appears within the area of the more pervious soils. The amount of water lost from canals, the excessive use of irrigation water, and the rainfall in this valley all indicate that a considerable part of the soil in the irrigated district is being filled with water and the appearance of seep spots clinches the arguments.

DRAINAGE.

The natural surface drainage of the delta is provided for to a limited extent by the Arroyo Colorado, a few resacas,[a] and depressions between the numerous resacas. The south side of the Arroyo Colorado has a low bank, and that stream naturally takes the surface drainage from a strip of land bounded on the south by the nearest resaca or the Rio Grande and on the north by the second lift lands. The drainage of the bottoms south of the Arroyo Colorado is inadequately provided for by broad, shallow depressions between the resacas. These depressions do not have a definite channel, but hold the water that settles into them until a large volume is collected, when part of it forces its way through the growth of mesquite and swamp grass to the Gulf, and the remainder stands in the low places until evaporated.

The resacas do not carry much drainage water, having high banks from which the ground slopes toward the depressions that lie between the resacas and have about the same elevations as the bottoms of these old watercourses. The bed of the Rio Grande is higher than a large part of the delta lands, and the slope is of course away from it. During flood periods the water breaks over the banks of the Rio Grande between Samfordyce and Run, at a point southwest of Olmito and near Brownsville. The water that breaks over the banks above Run flows north until it reaches a chain of old resacas, ponds, and lakes near the boundary of the second lift lands, then follows this until it reaches the upper end of the south fork of the Arroyo Colorado, known as Hooks Arroyo. If, however, the channel of this stream is not large enough to carry such water off, as is often the case, it moves northeastward, passing between Mercedes and Donna, until it reaches the north fork of the Arroyo Colorado, when part of the water passes through the fork around east of Mercedes and thence to the main arroyo, and the remainder continues northeastward toward the Gulf of Mexico, crossing the main line of the St. Louis, Brownsville and Mexico Railway near Lyford. If the overflow is small the sheet of water is not very wide, but as the depth of overflow increases the territory covered increases rapidly until, during a large flood, practically all of the bottom lands except the highest resaca banks are flooded. There are two flood periods in this part of the valley, one usually during April or May and the other during September. The flood water does not come from local rainfall, but from melting snow and rain in the mountains of Colorado and New Mexico and the Republic of Mexico. The largest floods occur when the rise coming from the upper Rio Grande is supplemented by flood water in the Mexican tributaries. The most important tributary in this respect is the Rio San Juan, which empties into the Rio Grande near Rio Grande City, Tex. The flood of September, 1909, was caused by a torrential rainstorm near Monterey, Mexico, on the headwaters of the Rio San Juan. The Rio Grande was already out of its banks when this flood reached it, and the result was an overflow of the bottoms considerably higher than any previously recorded. Nearly all of the irrigation canals in the valley were damaged more or less, especially those near the upper end of the delta. Flumes were torn out and in some places the levees forming the banks of the canal were swept away. People were forced to leave their dwellings temporarily, and in some cases the towns were flooded. The railroads, except upon the second lift which did not overflow, were covered with water several feet in depth and all traffic was stopped for some weeks. No attempt is made to give the money value of the loss sustained, but it will reach well into the hundreds of thousands of dollars. It is very evident that a levee along the Rio Grande is necessary to protect residents and property from a repetition of this flood. This will, of course, be a protection from flood water only, and the rainfall and waste irrigation water will have to be conducted into the Arroyo Colorado where possible and a system of drainage ditches provided between the resacas for the remainder.

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[a] A resaca is an old river channel that was probably cut off by an overflow scouring out a new and more direct course. Some of them were originally short loops in the river, but others are many miles in extent (see fig. 2, p. 10). Their top width varies from about 150 to 350 feet and their depth from 4 or 5 to 20 feet.

A drainage district has been organized near Brownsville to construct outlet channels for the territory lying north and east of Brownsville and Olmito. Two large ditches are contemplated, one starting west of the Ohio and Texas Sugar Company's plantation, extending eastward across it and thence in a northeasterly direction to an arm of the Gulf of Mexico; the other starting near Olmito and passing to the northeast through Tule Lake into an arm of the Gulf.

SOILS.

The soil in the overflow area varies from a silty clay loam to a heavy clay; and on the second lift lands, from a light fine sandy loam to a clay loam. In each case the soils grade gradually from the lightest to the heaviest, and it is difficult for the inexperienced person to distinguish between them, except by comparison. The soil in the overflow area may be divided into two distinct classes, the silty clay loam which occupies the higher elevations and is usually a strip of land bordering the resacas and extending from a few hundred feet to a half mile on either side, and the heavy clay soils which occupy the flat depressions between the resacas. The Bureau of Soils made a survey of a small area near Brownsville in 1907,[a] and since the types of soil found in that vicinity, with the exception of the swamp area, are similar in location and composition to those of nearly the entire overflow area, their observations are quoted quite extensively. With their permission, the soil survey map of the Brownsville area is incorporated in this report as figure 2. Reference to it will show the location of the two general types found in that area and give an idea of what may be encountered throughout the overflow section.

The Bureau of Soils says of the first type:

> The soil of the Laredo silty clay loam consists of a dark brown to black heavy silty loam to silty clay loam with an average depth of about 12 inches. It contains a large quantity of silt and clay, which causes the surface to bake and sun-crack to a considerable extent. The soil is sticky and plastic when wet, and the type as a whole has many of the characteristics of a soil of heavier texture. The subsoil, from 12 to 36 inches, is a light brown to drab silty clay loam, which becomes much lighter in color as the depth increases and usually contains a slightly higher percentage of silt and clay than the soil. The subsoil is sticky and plastic when wet, but when dry it becomes hard and compact and is easily crushed into a fine gray powder.
>
> The Laredo silty clay loam is easily reduced to a state of thorough cultivation. The surface breaks up into a loamy friable condition free from hard clod, and the well-cultivated areas always have a desirable tilth. This soil occurs in long narrow bodies which extend across the area, following closely the general course of the former channels of the Rio Grande. * * *
>
> The material from which this soil has been derived was deposited in the slower currents at times of overflow of the Rio Grande, during the time when the river occupied the abandoned channels near which the soil occurs. The areas occupied by this type of soil did not remain in a flooded condition during long periods and there was not that slow deposition of the finer materials in still or stagnant water, such as took place in the depressions. During times of overflow, however, a large amount of material was laid down nearer the stream and the silt, clay, and fine sand composing this soil were deposited in the quieter currents at a distance from the main channel.

This soil is frequently underlain near the resacas with a layer of sand from 1 or 2 to 12 feet in depth. The sand is finer and contains more silt as the distance from the resaca increases, until finally it changes to a silt loam or clay. The layer of sand is not always continuous or uniform in thickness but frequently is composed of more or less disconnected pockets. Observations show that water will move quite readily through both this soil and subsoil.

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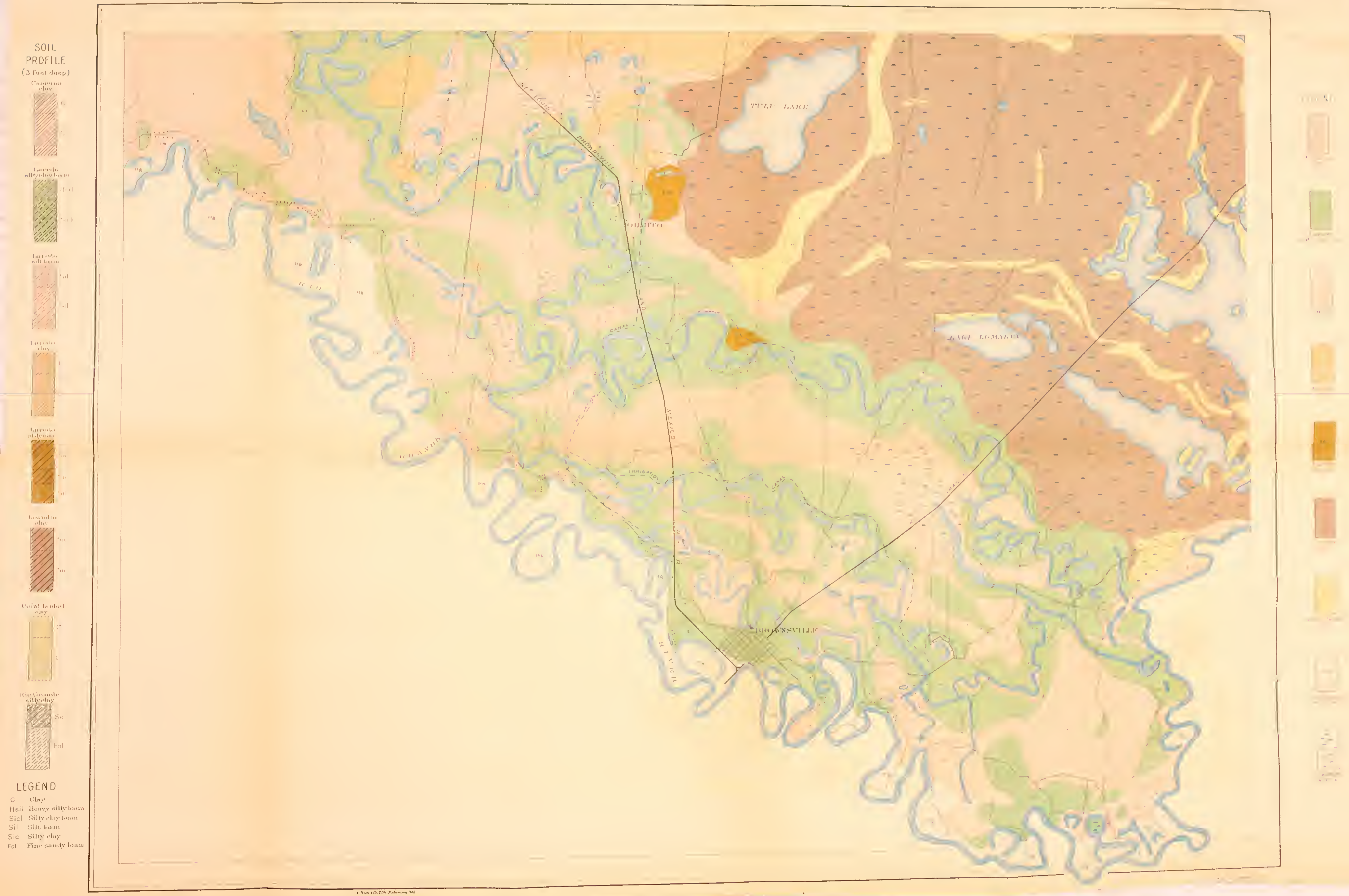
[a] U. S. Dept. Agr., Field Operations of the Bureau of Soils, 1907, p. 750.

U.S. DEPT. OF AGRICULTURE.
BUREAU OF SOILS.
MILTON WHITNEY, CHIEF.

SOIL MAP



The heavy clay is described by the Bureau of Soils as follows:

> The surface soil of the Cameron clay consists of a heavy dark brown to black clay which has an average depth of 12 to 15 inches. When wet, the soil is very sticky and tenacious, and on drying the surface bakes and sun-cracks to such an extent that thorough cultivation is almost impossible. The subsoil—12 to 36 inches—is a heavy clay which is slightly lighter in color than the surface soil, but contains a higher percentage of silt and clay. Small lime concretions are frequently encountered in the deeper subsoil.
>
> The surface of the better drained areas breaks up into a friable, loamy condition. The poorly drained areas are very difficult to cultivate, as they remain in a wet condition for long periods, and when dry the surface is so hard and baked that the cultivation of the soil is almost impossible. This soil occurs in areas of greater or less extent in almost every locality embraced by the survey. It occupies the broad, shallow basins which occur between the abandoned river channels, and as a whole it is very poorly drained. The lower portions of these broad, shallow depressions remain in a wet and flooded condition during the greater part of the year, as they receive the drainage water from the lands bordering them.

The heavy clay occupies the low poorly drained areas lying between the resacas and is found throughout the overflowed section. The subsoil is usually a heavy clay to a depth of 12 feet. Both the soil and subsoil are so finely divided and compact that water will move through them but slowly, and drains will have to be constructed close together.

The soil of most of the second lift lands is a brown to gray, fine sandy loam. The Bureau of Soils divides it into two classes, but as they will drain equally well the description of but one is quoted:

> The Brennan loam consists of 6 to 12 inches of a gray to light grayish-brown loam, sometimes approaching a heavy fine sandy loam on the one hand and a silt loam on the other. The lighter textured areas occur near the contact with the Brennan fine sandy loam, while the more silty portions are found where it has been developed away from the sandy soils and more closely associated with those of heavier texture, as in the vicinity of San Juan. Very little organic matter is present, and this, together with the very high lime content, often gives the surface the white, floury appearance characteristic of the Laredo silt loam. This soil bakes slightly, but under irrigation breaks up into a loose friable loam which is easily cultivated, a comparatively small amount of work yielding an ideal mellow seed bed.
>
> The subsoil has very much the same texture as the surface soil, consisting of a gray to almost white loam, containing a very high percentage of lime. Its very light color is largely due to the large amount of lime present.

It is said that in some localities the subsoil is sandy for 50 feet in depth and water will readily pass downward to that depth. In other localities, however, a layer of heavy clay is encountered at from 8 to 12 feet below the surface, preventing the ready downward passage of water.

The clay loam of the second lift lands is limited in extent and found only in the low places. It is a loose soil that dries quite rapidly and pulverizes easily. The subsoil is composed of the same material but is lighter in color. Both soil and subsoil will allow the ready passage of water and should drain easily.

Some of the heavy clay subsoils are used in the manufacture of brick, and from all appearances will make reasonably good tile. Most of the brick made therefrom would not stand the standard test usually applied to building brick, but they appear to be satisfactory in this climate, and it is quite probable that the same will be true of tile. A tile factory is now being built at Brownsville and in the near future its product will be available.

CROPS GROWN.

The staple crops now grown are cotton, corn, sugar cane, alfalfa, forage crops, fruit, and truck. Rice was quite profitably grown for a few years, but the concentration of alkali caused by the flooding of the fields, and evaporation, reduced the yield to such an extent that it became unprofitable. The topography of the broad level flats of heavy clay between the resacas is such that the land could be prepared for the culture of rice without much expense. In most cases all that was necessary was to construct a levee along a contour or in checks close enough together so the plat thus laid out could be flooded with water to a uniform depth. At first no drainage was attempted and the heavy clay soil prevented the percolation of any large amount of water so that the conditions appeared to be ideal, and had it not been for the alkali present in the soil, would have been ideal for the growth of rice. But the salt concentrated steadily until, by the third year, it invariably became unprofitable to grow rice. Soil sample No. 8, analysis of which is given in the table on page 16, may be taken as a typical analysis of the heavy clay soil before it has been irrigated extensively, and sample No. 17, analysis of which is given in the table on page 18, may be taken as typical after three years' flooding for rice. The former contains an average of 0.168 per cent of soluble salts in the first 4 feet of soil, while the latter contains 0.570 per cent of the sulphates and chlorids alone in the first 4 feet and 0.875 per cent in the second 4 feet of depth.

The history of rice culture in the Rio Grande Delta may be summed up as follows: First year, extra good crop, above average; second year, average crop; third year, 30 per cent of average crop; fourth year, land abandoned.

It should be stated, however, that in one instance at least, where a system of shallow ditches was constructed, the land was freed from sufficient alkali to permit the raising of 65 per cent of an average crop the fourth year. (See p. 29.)

Sugar cane has been grown to a limited extent in the lower Rio Grande Valley for nearly thirty years. The plantations on which it has been grown for any length of time are located on the river or a resaca bank where the soil is open. As a rule the irrigation water is pumped direct from the river, so that no large supply canals, in which water could stand and from which any large amount could seep into the ground, are necessary. Moreover, these soils are usually underlain by a sandy stratum that affords more or less adequate natural drainage. When there is not a constant source of seepage water to fill this layer of sand it will usually carry away the rain and ordinary irrigation water rapidly enough to prevent the forming of a water table sufficiently near the surface for evaporation to concentrate the alkali it may contain. These old cane plantations are not free from alkali; in fact, some of them contain quite extensive spots on which the cane has been killed out and on which not even salt grass will grow.

The history of sugar cane on the heavy clay soils without deep drainage is another and far different story. In fact, it compares closely with that of the rice industry; the crop deteriorates steadily until it becomes unprofitable and has to be abandoned. Soil sample No. 10, analysis of which is given in the table on page 16, containing an average of 0.916 per cent of soluble salts in the first 5 feet of depth, shows what may be expected after three or four years' irrigation, especially if surface water is not rapidly removed.

Sorghum cane, oats, cotton, sugar cane, and old alfalfa are quite resistant to alkali and can be grown where the more tender crops can not. Of the fruits, grapes, olives, and figs, and of the truck crops, onions, potatoes, and radishes are the most resistant.

RAINFALL.

The rainfall in the lower Rio Grande Valley is extremely varied and uncertain. The records kept at Fort Brown show the maximum yearly rainfall to be 60.7 inches, the minimum 8.9 inches, and the mean 28.2 inches. The maximum monthly rainfall recorded is 30.57 inches for September, 1886. The maximum daily rainfall given, 11.91 inches, occurred in the same month and was part of a 48-hour storm during which 22.23 inches of water fell. A precipitation of 5 inches in twenty-four hours is not unusual and 2 inches in twenty-four hours is a common occurrence. The rainfall usually comes in heavy storms with light scattering showers between. In 1908 the precipitation was 26.62 inches, about three-fifths of which fell in seven storms and nearly one-third of which fell in two storms.

If the rainfall were evenly distributed it would be sufficient for a great many crops, provided the soil were carefully handled, but it is so erratic that the risk is too great. In the natural state the country supports only a growth of cactus and mesquite. The heavy dashes of rain usually fill up the low depressions between the resacas, where the water stands until evaporated. If crops are to be grown on these lower lands a system of deep drainage ditches is necessary, not only to carry off the rain water but also to furnish an outlet for seepage and excessive irrigation water.

ALKALI.

KINDS AND QUANTITIES ALLOWABLE.

The most common injurious alkaline salts are the following: Sodium chlorid (common salt), sodium sulphate (Glauber's salt), magnesium sulphate (Epsom salt), calcium chlorid, calcium sulphate (gypsum), and sodium carbonate (sal soda). The first five are usually called white alkali, due to the white efflorescent crust that appears upon the surface of the ground when either is present in large quantities; and the latter, black alkali, due to the black crust that appears when it is present in large amounts. When a large amount of calcium is combined with the sodium chlorid the stain becomes brown or even black and is occasionally mistaken for sodium carbonate. But the calcium-sodium chlorid stain has a moist, slippery appearance, due to the strong attraction of the salts for moisture, while the sodium carbonate stain is of a lighter, more feathery appearance, and is formed by the action of this alkali on the humus of the soil, which it dissolves.

Injurious alkaline salts are usually considered under three heads, namely, sulphates, chlorids, and carbonates, of which the sulphates are the least injurious and the carbonates the most injurious to plant life. Hilgard says:[a]

> Since the maximum percentage that can be resisted by plants varies materially with the kind of soil, it is difficult to give exact figures, save with respect to particular cases. For the sandy soil of the Tulare substation, California, for instance, the maximum for cereals may be approximately stated to be .1 per cent for sal soda; .25 per cent for common salt, and from .45 to .5 per cent for Glauber's salt. For clay soils the tolerance is in general markedly less, especially as regards the sal soda.

The Bureau of Soils makes the following statement:[b]

> Soil containing from 0.60 to 1 per cent of total salts is almost worthless for general farming or fruit growing, but by continued effort some of the most resistant crops may be grown.

In all of the analyses of soils in the lower Rio Grande Valley the chlorids and sulphates predominate, the carbonates being present in small quantities only. In most cases the chlorids are present in larger amounts than the sulphates, and of the chlorids, sodium chlorid (common salt) predominates, especially in the heavy soils. The elements present in the soils of this section and their probable combinations under natural conditions should cause no alarm, as soil containing not more than 0.15 per cent or 0.20 per cent of total soluble salts is not considered dangerous. Should, however, the amount run much above 0.20 per cent, the soil should be handled with care and the farmer should realize that his soil is nearing the danger point.

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[a] Soils. New York and London, 1907, p. 464.

[b] U. S. Dept. Agr., Bur. Soils Bul. 35, p. 24.

ALKALI CONTENT OF SOILS OF LOWER RIO GRANDE VALLEY.

All soils in arid and semiarid countries contain more or less alkali and the lower Rio Gránde Valley is no exception to this rule. It is found throughout this section in varying quantities and various degrees of concentration, from a glistening crystalline form near the coast to a brown stain on the second lift lands, where it has been collected by seepage water. Chemical analyses show that in the well-drained sandy lands the alkali is usually so distributed by nature as not to be injurious to plant growth, but that it is present in sufficient quantities to destroy plants if allowed to concentrate by the action of seepage water or evaporation from a water table near the surface. In the low-lying heavy soils, where the water stands a large part of the time, the alkali is much more concentrated, especially in the deeper subsoils. These soils should be handled with the utmost care, since there is a constant supply of alkali to be dissolved by water and brought up by evaporation. This is noticeable on the old rice fields, where is was concentrated to such an extent that rice growing was discontinued, and in some places vegetation will not grow after the land has been lying idle and leaching for three years. Even in some cases where this heavy land had been cropped in sugar cane and watered judiciously, the growth of the cane became less vigorous each year, until at the end of three or four years it had to be abandoned.

Complaint is frequently made that the heavy soils deteriorate with each successive crop, until at the end of two or three years it is barely profitable to cultivate them, even where no alkali stain is visible or where there is no water table within 6 or 8 feet of the surface and where seeds germinate reasonably well. Samples of this class of soil were taken and analyses were made by the Bureau of Soils. They are given as Nos. 2, 3, and 4 in the table following.

Soil analyses for alkali content.

[Samples taken from Lower Rio Grande Valley by Drainage Investigations, 1909. Analyses made by Bureau of Soils.]

No.	Bureau of Soils identification number.	Depth.	Soluble salts by analysis.	Ca.	Mg.	Na.	K.	SO_4.	Cl.	HCO_3.
		Inches.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
1	20403-1	0-12	0.10	......	......	......	....	......	......	....
	20404-2	12-24	.08	......	......	......	....	......	......	....
	20405-3	24-36	.13	......	......	......	....	......	......	....
2	20406-4	0-12	.25	0.040	0.005	0.025	....	0.038	0.028	0.114
	20407-5	12-24	.19	......	......	......	....	......	......	....
	20408-6	24-36	.18	......	......	......	....	......	......	....
	20409-7	36-48	.17	......	......	......	....	......	......	....
3	20410-8	0-12	.20	......	......	......	....	......	......	....
	20411-9	12-24	.22	......	......	......	....	......	......	....
	20412-10	24-36	.34	.039	.008	.065	....	.077	.122	.034
	20413-11	36-48	.33	......	......	......	....	......	......	....
4	20414-12	0-12	.24	.035	.005	.025	....	.034	.025	.121
	20415-13	12-24	.13	......	......	......	....	......	......	....
	20416-14	24-36	.13	......	......	......	....	......	......	....
	20417-15	36-48	.15	......	......	......	....	......	......	....
5	20418-16	0-12	.21	.035	.005	.019	....	.040	.035	.079
	20419-17	12-24	.14	......	......	......	....	......	......	....
	20420-18	24-36	.11	......	......	......	....	......	......	....
	20421-19	36-48	.09	......	......	......	....	......	......	....
	20422-20	48-60	.10	......	......	......	....	......	......	....
6	20423-1	0-12	.218	.029	.006	.020	....	.036	.007	.120
	20424-1	12-24	.144	......	......	......	....	......	......	....
	20425-1	24-36	.164	......	......	......	....	......	......	....
	20426-1	36-48	.210	......	......	......	....	......	......	....
7	20427-2	0-12	.166	......	......	......	....	......	......	....
	20428-2	12-24	.154	......	......	......	....	......	......	....
	20429-2	24-36	.126	......	......	......	....	......	......	....
	20430-2	36-48	.120	......	......	......	....	......	......	....
8	20431-3	0-12	.144	......	......	......	....	......	......	....
	20432-3	12-24	.154	......	......	......	....	......	......	....
	20433-3	24-36	.160	......	......	......	....	......	......	....
	20434-3	36-48	.216	......	......	......	....	......	......	....
9	20435-4	0-12	1.191	.047	.017	.328	....	.460	.231	.108
	20436-4	12-24	.674	......	......	......	....	......	......	....
	20437-4	24-36	.693	.011	.005	.202	....	.270	.049	.156
	20438-4	36-48	.500	......	......	......	....	......	......	....
	20439-4	48-60	.634	......	......	......	....	......	......	....
	20440-4	60-72	.440	......	......	......	....	......	......	....
10	20442-5	0-12	.629	.043	.008	.171	....	.140	.119	.148
	20443-5	12-24	.462	......	......	......	....	......	......	....
	20444-5	24-36	.794	.003	.005	.246	....	.160	.140	.240
	20445-5	36-48	1.180	......	......	......	....	......	......	....
	20446-5	48-60	1.516	......	......	......	....	......	......	....
11	20934-4	0-12	.11	.010	......	.045	....	......	......	.055
	20935-4	12-24	.13	.013	......	.052	....	......	.013	.052
	20936-4	24-36	.10	.008	......	.039	....	.004	.011	.038
	20937-4	36-48	.12	.010	......	.045	....	.021	.011	.033
12	20938-5	0-12	.10	.003	......	.047	....	......	.010	.040
	20939-5	12-24	.12	.028	......	.038	....	......	.036	.018
	20940-5	24-36	.10	.014	.002	.033	....	......	.034	.017
	20941-5	36-48	.11	.015	......	.036	....	......	.015	.044
13	20942-6	0-12	.15	.046	......	.026	....	......	.052	.026
	20943-6	12-24	.09	......	......	.046	....	......	.015	.029
	20944-6	24-36	.29	.009	......	.113	....	......	.069	.069
	20945-6	36-48	.09	.006	......	.037	....	......	......	.047
14	20946-7	0-12	.09	......	.010	.035	....	......	......	.045
	20947-7	12-24	.10	.029	.006	.015	....	.015	......	.035
	20948-7	24-36	.26	.059	......	.072	....	.013	.080	.036
	20949-7	36-48	.42	.054	......	.154	....	......	.144	.068
15	20950-8	0-12	.14	.023	......	.048	....	......	.042	.027
	20951-8	12-24	.12	......	......	.017	0.040	......	.003	.060
	20952-8	24-36	.19	.005	.053	.026	.005	......	......	.101
	20953-8	36-48	.20	......	......	.100	....	.020	.020	.060
16	20441	....	17.569	.610	.055	5.440	Trace.	9.66	1.68	.124

Sample No. 2 was taken from land that had been irrigated two full years with about 15 irrigations; No. 3 from land that was newly cleared and had never been irrigated; and No. 4 from land that had been irrigated one full year. No. 2 shows an average of 0.175 per cent; No. 3, an average of 0.27 per cent; and No. 4, an average of 0.16 per cent of total soluble salts in the first 4 feet. This would indicate that there was more alkali in the soil that had never been cropped than in either of the others, but since this is from but one boring in each place too much dependence should not be placed upon it. It should be noted, however, that there is a tendency toward a concentration of the alkali in the surface foot after irrigation and that there is less in the surface foot in the unirrigated land than in any of the others. Any further concentration of the alkali near the surface should be stopped by copious irrigation and careful cultivation. Under such treatment it may be necessary to supply underdrainage to assist in the removal of the ground water that is liable to accumulate in this type of soil.

Sample No. 5 was taken from the second lift within about 50 feet of an irrigation lateral. This soil is underlain at about 7 feet deep by a heavy, highly impervious clay that prevents the ready downward passage of the water. In this case the ground water was within about 2½ feet of the surface and a marked alkali stain was noticeable. Trees were dying and all the truck plants had been killed. The amount of alkali in this soil, if evenly distributed, is not excessive; and it is probable that the ground water was the cause of the injury to the trees, while most of the alkali in the surface foot was concentrated just at the surface in sufficient quantities to kill ordinary plants. If half of the alkali in the surface foot were concentrated in the surface inch it would make 1.26 per cent, which would prevent seed from germinating and would kill any ordinary plant.

Samples Nos. 1, 6, 7, 11, 12, 14, and 15 were taken from the light soil; No. 7 from land that had never been irrigated or cropped; Nos. 14 and 15 from land that had never been irrigated but had been cropped two full years by the dry-farming method; Nos. 6, 11, and 12 from land that had been irrigated and cropped for two full years. None of these samples shows enough alkali to kill crops, unless that contained in the surface foot is concentrated at the surface of the ground, and even then it can probably be distributed again by irrigation and deep cultivation, but there may be enough to seriously injure them. Samples Nos. 8 and 13 were taken from a heavy clay soil, with good surface drainage, that had been carefully irrigated and cropped one and one-half years. Sample No. 10 was taken from a very heavy clay soil, poorly drained, that had been heavily irrigated two years and carefully irrigated for one year. The third crop of sugar cane was then being grown. It was about half grown, off some in color, and did not promise a profitable yield. Sample No. 9 was taken from a light (resaca) soil with a water table from 1½ to 2 feet below the surface. There was a heavy alkali crust on the surface and no vegetation except some scattering bunches of salt grass. Analyses of two types of soils at different depths, samples of which were collected by Drainage Investigations of this Office and analyzed by the Bureau of Chemistry, are given in the following table:

Soil analyses for alkali content.

[Samples taken from Lower Rio Grande Valley by Drainage Investigations, 1906. Analyses made by Bureau of Chemistry.]

No.	Depth in inches.	Chlorids and sulphates.	Sodium sulphate.	Sodium chlorid.	Calcium chlorid.
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
17	0-12	0.500	0.035	0.102	0.363
	12-24	.424	.036	.128	.260
	24-36	.670	.046	.187	.437
	36-48	.687	.064	.270	.353
	48-60	.759	.068	.387	.304
	60-72	.818	.139	.567	.112
	72-84	.873	.191	.583	.099
	84-96	1.050	.280	.662	.108
18	0-12	.038	.020	.009	.009
	12-24	.145	.047	.089	.009
	24-36	.493	.119	.370	.004
	36-48	.709	.166	.543	.000
	48-60	.940	.210	.730	.000
	60-72	1.014	.222	.792	.000
	72-84	.903	.210	.684	.000
	84-96	1.097	.337	.738	.022

Sample No. 17 was taken from a medium heavy clay soil, underlain with sand and supplied with shallow drainage ditches having a poor outlet. The land had been flooded and cropped with rice for two years and had then lain idle for one year when the sample was taken. The alkali had been drawn up and distributed through the soil near the surface in sufficient quantities to prevent the growth of any ordinary vegetation. There was also a crust on the surface. Sample No. 18 was taken from the same kind of soil as No. 17, but it had produced only one crop of rice. This soil raised a crop of rice the second year. There is nearly the same amount of alkali in the first 8 feet of the soil from which the two samples were taken, but in No. 18 it had not been drawn up sufficiently to prevent the growth of plants, while in No. 17 it had. It is noticeable in both Nos. 17 and 18 that the percentage of sodium chlorid apparently increases with the depth and that the calcium chlorid decreases with the depth. The calcium chlorid may concentrate more rapidly than the sodium chlorid, or its distribution in this case may be due to some local conditions.

Analyses by Dr. G. S. Fraps, of the Texas Experiment Station, of samples taken near Mercedes by Mr. W. L. Rockwell, of Irrigation Investigations of this Office, are given in the following table:

Soil analyses for alkali content.

[Samples taken by Irrigation Investigations, 1908. Analyses made by Dr. G. S. Fraps.]

No.	Irrigation, Investigations identification number.	Depth.	Total soluble salts.	Chlorin.	Sulphur oxid.	Calcium carbonate.	Calcium oxid.	Magnesium oxid.	Calcium sulphate.	Calcium chlorid.	Magnesium chlorid.	Sodium chlorid.	Magnesium carbonate.	Sodium carbonate.
		In.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
19	Lot 12, block 65.	0–12	0.064	0.006	0.004	0.035	0.018	0.001	......	......	......	......	......	......
		12–24	.064	.014	.007	.027	.014	.002	......	......	......	......	......	......
20	Lot 16, block 82.	0–12	.064	.007	.005	.031	.018	.003	......	......	......	......	......	......
		12–24	.074	.004	.007	.038	.020	.005	......	......	......	......	......	......
21	Lot 3, block 81..	0–12	.040	.004	.004	.025	.004	.003	......	......	......	......	......	......
		12–24	.065	.009	.003	.033	.017	.003	......	......	......	......	......	......
22	Lot 6, block 71..	0–12	.059	.013	.005	.022	.014	.005	......	......	......	......	......	......
		12–24	.166	......	......	.023	......	......	0.027	0.067	0.024	0.025	......	......
23	Lot 8, block 75..	0–12	.085	.014	.010	.039	.012	.010	......	......	......	......	......	......
		12–24	.079	......	......	.021	......	......	......	......	......	.030	0.009	0.019
24	Lot 8, block 77..	0–12	.065	.019	.003	.024	.016	.003	......	......	......	......	......	......
		12–24	.145	......	......	.020	......	......	.022	......	.022	.081	......	......

Of the analyses reported in the table, Nos. 19, 20, and 21 are of the loam soil and 22, 23, and 24 are of the heavy type. None of these soils contains enough alkali in the first 2 feet to harm plant growth, but if it should be concentrated at the surface by seepage or evaporation from ground water there is probably enough to ruin crops.

Samples Nos. 16 and 25 were alkali crusts which were analyzed for the purpose of determining the predominating alkalis present. No. 16 was taken from a resaca soil. No. 25 was taken 1 mile northeast of Olmito, and the analysis as reported by the Bureau of Soils is as follows:

Alkali analysis for proportion of constituents.

[Sample collected and analysis made by Bureau of Soils, 1907.[a]]

No.	Ions.	Per cent.	Conventional combination.	Per cent.
25	Calcium (Ca)	12.66	Calcium sulphate ($CaSO_4$)	14.09
	Magnesium (Mg)	3.04	Calcium chlorid (CaCl)	23.53
	Sodium (Na)	19.03	Magnesium chlorid ($MgCl_2$)	11.92
	Potassium (K)	.94	Potassium chlorid (KCl)	1.80
	Sulphuric acid (SO_4)	9.94	Sodium bicarbonate ($NaHCO_3$)	.97
	Chlorin (Cl)	53.68	Sodium chlorid (NaCl)	47.65
	Bicarbonic acid (HCO_3)	.71		
	Carbonic acid (CO_3)	....	Per cent soluble	3.39

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[a] This table and the quotations immediately following same are from U. S. Dept. Agr., Field Operations of the Bureau of Soils, 1907, pp. 729, 730.

> Alkali occurs in sufficient amounts to be harmful to crops in almost every section of the area where water collects and stands for long periods of time and where the natural drainage is so poor that this water is removed only by evaporation. * * * As the water evaporates the alkali held in solution by the waters which thoroughly saturated the soil and deeper subsoil, and also that contained in the seepage water from the surrounding land, becomes concentrated in the surface soil, often causing it to contain such a high percentage of soluble salts that it supports only a growth of coarse salt grass. The greater quantity of alkali seems to occur in the deeper subsoil, and when these low-lying areas are flooded, either naturally or by irrigation, and no provision is made to drain them thoroughly, accumulations of alkali soon appear on the surface and the agricultural value of the land is greatly decreased.

MOVEMENT OF WATER AND ALKALI IN SOILS.

A few of the fundamental principles of the movement of water and mineral salts in the soil may well be considered to assist the agriculturist in understanding the problems he may have to solve.

Water in the soil is usually divided into two classes—hydrostatic water and capillary water. Hydrostatic water is that which occupies the space between the particles of soil and is free to respond to the forces of gravity when an outlet is provided. It is the water that is visible when land becomes water-logged or swamped, and is called gravity or drainage water. Capillary water is that which clings closely to the particles of soil by a force called surface tension, and is not affected by gravity. It is the water that remains when land is drained.

Hydrostatic water moves along the line of least resistance under the force of gravity, but capillary water moves in any direction, due to the attraction that exists between solids and liquids.

Soil is composed of a great many particles, and the openings or voids between them vary from 30 to 60 per cent of the whole space occupied by a given amount. When there is only a small amount of moisture in the soil the film of capillary water surrounding each particle is very thin, but as water is added it thickens up until finally the voids are filled and practically all of the air is excluded. Plants get their nourishment from the mineral matter, organic matter, and gases held in solution by the capillary water, but since air is necessary for the formation of plant food it is readily seen that if the voids are filled with water the plant can not exist.

The soluble salts (alkali) of decomposed rock are found in varying quantities in all arid and semiarid countries, and it is a noticeable fact here, as in other irrigated countries, that when an excess of water is allowed to stand on the surface, enter the ground, and be evaporated from the surface, or seep through a substratum of porous material near the surface, alkali is likely to accumulate in sufficient quantities to injure plant growth. The movement of mineral salts in the soils is usually in the direction of the capillary water. When water is applied to the surface it passes downward through root channels, worm burrows, and cracks in the soil, but when it is drawn in any direction by surface tension it passes through the smallest capillary openings in the soil. As it is drawn up by evaporation it brings with it in solution some of the mineral salts that were contained in the small openings and not molested by the water in its passage downward. It is therefore evident that to prevent the alkali concentrating at the surface it is necessary to put more water downward through the soil than is allowed to come up through it.

The location of alkali in the soil varies during the year, owing to the rainfall and the depth to which it will penetrate the ground. If the land is irrigated, the alkali will vary between irrigations, going down with the water and coming back with it as it is drawn up by surface tension, due to evaporation at or near the surface. It must be remembered that only a part of the alkali is moved downward and back in this manner and that more always comes up than goes down unless there be either natural or artificial drainage. The coarser the soil the deeper the line of concentration of salts will be lowered by rain or irrigation water. It is not probable that a large amount of salt will be washed down more than a foot or two in the heavy clay soils, and since surface tension will draw it up from a depth of 4 or 5 feet it is evident that in time the salt will be concentrated near the surface.

The problem of the farmer is to prevent the accumulation of a harmful amount of the salts near the surface, or, if they have already accumulated, how to remove the surplus so that crops can be profitably grown. It must be remembered that it is the concentration of alkaline salts that injures the growth of plants, and that every possible means must be used to prevent the accumulation of an injurious amount. This accumulation may be caused by the evaporation of ordinary rain and irrigation water, or by evaporation from a water table when it is near enough to the surface for capillary attraction to draw water up. If, after being cultivated two or three years, the crops look yellow and do not grow as well as formerly, it will be well to have the soil analyzed in order to ascertain whether or not the deterioration is due to a concentration of salt near the surface. If, after a rain, seed that was lying dormant germinates and the crop looks greener and fresher than before, it is quite probable that alkaline salts are accumulating near the surface, even though no stain or crust be visible. If a water table is formed, evaporation will be rapid and a stain will soon appear on the surface. In either case drainage should be provided so water will pass down through the soil and be removed from below. In its downward passage the water will leach out some of the soluble salts, and if enough be applied it will in time reduce the harmful accumulation so that crops can be grown. Provision should always be made to carry away the surplus irrigation and rain water, and fields should be carefully watched to detect the first signs of seepage. Perhaps the most prolific cause of the concentration of alkali in this section of the country is seepage water. Water moving through the soil dissolves and collects a large amount of mineral matter and when brought to the surface by capillary action evaporates, leaving the salt on the surface, where in time it may accumulate to the detriment of plant growth. Seepage water should always be cut off before a harmful water table is formed.

Where there is not good drainage, cultivation and the formation of a dry mulch will lessen evaporation, and hence the accumulation of alkali at the surface, and judicious irrigation will delay the formation of a water table and prolong the period of profitable cultivation. On the other hand, if there is good drainage, copious irrigations will tend to wash out any alkali that may be in the soil.

SOLUBLE SALTS IN SANDY AND HEAVY GUMBO SOILS.

The relative movement of alkali in a light soil with good natural drainage and in a heavy gumbo soil with poor drainage is well illustrated in the following tables taken from a Farmers' Bulletin of this Department.[a] The first table gives the results of salt determinations in a well-drained sandy soil irrigated for ten or twelve years; the second gives the results for a heavy gumbo soil.

Soluble salt content in sandy soil.

Depth in feet.	Unirrigated.				Irrigated.					
	Boring 62.		Boring 64.		Boring 26.		Boring 27.		Boring 28.	
	Per cent.	Pounds per acre-foot.	Per cent.	Pounds per acre-foot.	Per cent.	Pounds per acre-foot.	Per cent.	Pounds per acre-foot.	Per cent.	Pounds per acre-foot.
0-1	0.033	1,155	0.042	1,470	0.046	1,610	0.038	1,330	0.033	1,155
1-2	.019	665	.041	1,435	.049	1,715	.045	1,575	.037	1,295
2-3	.045	1,575	.035	1,225	.052	1,820	.044	1,540	.028	980
3-4	.027	945	.038	1,330	.066	2,310	.051	1,785	.030	1,050
4-5	.032	1,120	.045	1,575	.097	3,395	.060	2,100	.048	1,680
5-6	.028	980	.055	1,925	.106	3,710	.051	1,785	.048	1,680
6-7	.019	665	.056	1,960	.128	4,480	.064	2,240	.048	1,680
7-8	....	....	.170	5,950	.147	5,145	.070	2.450	.047	1,645
8-9	....	....	.238	8,330	.112	3,920	.049	1,715	.047	1,645
9 10	....	....	.243	8,505	.112	3,920	.049	1,715	.047	1,645
10-11	....	....	.205	7,175	.056	1,960	.072	2,520	.044	1,540
11-12	....	....	.120	4,200	.056	1,960	.072	2,520	.044	1,540
12-13	....	....	.163	5,705	.058	2,030	.072	2,520	.044	1,540
13-14	....	....	.228	7.980	.058	2,030	.072	2,520	.044	1,540
14-15	....	....	.178	6,230	.058	2,030	.072	2,520	....	....

Soluble salt content in heavy gumbo soil.

Depth in feet.	Unirrigated.		Irrigated.					
			Boring 36.		Boring 49.		Boring 52.	
	Per cent.	Pounds per acre-foot.	Per cent.	Pounds per acre-foot.	Per cent.	Pounds per acre-foot.	Per cent.	Pounds per acre-foot.
0-1	0.035	1,225	0.757	24,710	0.792	27,720	0.229	8,015
1-2	.038	1,330	.714	24,570	.920	32,200	.191	6,685
2-3	.054	1,890	.634	21,105	.944	33,040	.182	6,370
3-4	.200	7,000	.612	21,035	.792	27,720	.175	6,125
4-5	.333	11,655	.589	20,965	.519	18,165	.159	5,565
5-6	.337	11,795	.187	6,650	.519	18,165	.213	7,455
6-7	.253	8,855	....	....	.357	12,495	....	....
7-8	.253	8,855	....	....	.357	12,495	....	....
8-9	.282	9,870	....	....	.292	10,220	....	....

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[a] U. S. Dept. Agr., Farmers' Bul. 88.

A mechanical analysis shows that this heavy soil is somewhat lighter than the heavy clays of the Rio Grande Delta and should be more easily drained. The former contains approximately 36 per cent of fine sand and 40 per cent of silt and clay, while the latter contains but 1.5 per cent of fine sand and 98 per cent of silt and clay. It is therefore evident that the clays in the Rio Grande Delta, underlain with alkali as they are, may be expected to accumulate a sufficient amount of salt near the surface to prevent the growth of plants unless they have thorough drainage.

ALLOWABLE SALT CONTENT OF IRRIGATION WATER.

The allowable salinity of irrigation water depends upon so many variable quantities that it is almost impossible to say what amount will be safe. If the water contains sodium carbonate, or if the soil it is used upon be heavy and poorly drained or contains much salt, a large percentage of alkali will prove disastrous. According to Hilgard [a] 40 grains of soluble salts per gallon (68 parts per hundred thousand) is the usual limit for irrigation water, and that "it has been found in California that practically the upper limit of mineral content for irrigation water *under the ordinary practice* lies below 70 grains per gallon in *all* cases."

The following statement [b] gives a much larger amount as the limit of the salt content of irrigation water: "Five hundred parts of soluble matter may be taken as the extreme limit of endurance for plants, while 250 or 300 parts mark the danger point at which the results of the use of the water are very uncertain." In this statement the amounts given are parts per hundred thousand. On the light sandy soils of the Pecos Valley alfalfa and grapes were successfully irrigated during the season of 1909 with water the salt content of which runs as high as 400 parts per hundred thousand.

SALT CONTENT OF RIO GRANDE WATER.

The following table gives the analyses of six samples of water taken from the Rio Grande at the South Texas Garden, Brownsville, Tex., by Prof. E. C. Green. The analyses were made by Dr. G. S. Fraps, of the Texas Experiment Station. Sample No. 1 was taken March 1, 1908, when the water surface of the river was 15 feet below the bank; sample No. 2, April 13, 1908, water surface 7 feet 5 inches below the bank; sample No. 3, April 23, 1908, river bank full; sample No. 4, December 18, 1908, lowest stage of river; sample No. 5, May 2, 1909, water 17 feet below bank; sample No. 6, March 14, 1910, river lowest in three and one-half years.

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[a] Soils, p. 248.

[b] U. S. Dept. Agr., Bureau of Soils Circ. 10, p. 1.

Analyses of Rio Grande water.

[Results are given in parts per million.]

Sample.	Calcium carbonate.	Calcium sulphate.	Calcium chlorid.	Magnesium chlorid.	Magnesium sulphate.	Sodium chlorid.	Sodium sulphate.	Total alkali salts.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
No. 1	110	190			140	401	117	658
No. 2	225	9	107	131				238
No. 3	404	261	4	62		56		122
No. 4	91	216		74	95	229		398
No. 5	160	78			275	407		682
No. 6	135	88			240	370	60	670

An analysis by the Bureau of Soils of a sample of Rio Grande water taken about 5 miles southeast of Brownsville when the river was very low and the quantity of silt probably abnormally small is as follows:

Analysis of Rio Grande water.

	Parts per 100,000.
Silt in suspension	28.0
Total dissolved salts	96.0
Sodium bicarbonate (calculated from HCO_3)	18.5
NaCl (calculated from Cl)	24.2

The samples of water, analyses of which are given in the table below, were taken from the Rio Grande at Brownsville by the writer for Mr. E. B. Cushing and analyzed for him by Mr. P. S. Tilson, chemist for the Houston Laboratory. The samples were taken near the middle of the stream where the water was about 4 feet deep. Two were taken at the surface and two at one-half the depth. The stage of the river was about 0.5 foot above the lowest known.

Analyses of Rio Grande water.

IN SAMPLES TAKEN AT SURFACE.

Sample.	Salts in solution.			
	Kinds.	Amounts.		
		Grains per gallon.[a]	*Per cent.*	*Parts per million.*
A	Sodium chlorid	15.385	0.027	265
	Sodium carbonate	8.165	.014	140
	Sodium sulphate	4.833	.008	83
B	Sodium chlorid	15.385	.027	265
	Sodium carbonate	9.914	.017	170
	Sodium sulphate	6.254	.011	107
IN SAMPLES TAKEN AT HALF THE DEPTH OF THE WATER.				
C	Sodium chlorid	17.307	0.030	298
	Sodium carbonate	7.581	.013	130
	Sodium sulphate	3.516	.0006	60
D	Sodium chlorid	17.307	.030	298
	Sodium carbonate	8.749	.015	150
	Sodium sulphate	4.650	.008	80

[a] United States gallon, 231 cubic inches.

It is readily seen from the foregoing tables that with two exceptions the amount of alkali in the water falls below the safe limit of the most conservative authority quoted, and in those instances they fall below the extreme limit set by him. It is therefore safe to state that with reasonably good drainage the Rio Grande water is good irrigation water even at the lowest stages of the river.

RISE OF GROUND WATER IN SOILS.

The rise of ground water is caused by putting more water into the ground than the subsoil will carry away. Nearly all subsoils will allow a flow of water, but in some cases the material composing them may be so compact that the water moves very slowly, and for all practical purposes a storage reservoir is formed. This is especially true where waves of highly impervious clay, or ridges of shale or rock, occur in such a manner as to cut off the underground flow. If the strata of subsoil are composed of a porous material, and are continuous, the underground flow may be considerable. In some cases where there is a good slope to both the soil and the layers of subsoil, and where the latter is of a sand or gravel formation and where irrigation water is used judiciously, land may be cultivated indefinitely without the ground water rising enough to cause injury to crops. But such cases are rare, since seepage waters from canals or higher lying more pervious irrigated lands, or an excessive use of irrigation water, usually supply a greater amount than will pass off through the subsoil. If this is the case the ground water will rise slowly but surely unless artificial drainage be supplied. The subsoil should be considered as a natural drain, and if it be deficient, assistance must be rendered by providing artificial drains.

A careful study of the situation in the Pecos Valley, at Barstow, Tex., shows that the permanent water table was originally 20 to 30 feet below the surface, while, after 12 or 14 years of irrigation, ground water had in some instances risen to and run off over the surface, making a system of extensive outlet ditches necessary. Borings show that in some cases gypsum ridges cross the valley, shutting off the natural underflow to a greater or less extent and causing the ground water above them to rise to, or nearly to, the surface. In other instances the subsoil is practically free from these ridges, and the rise of the water table was caused by seepage from canals and excessive irrigation. Observations made by a reliable hydraulic engineer show that in some instances water was run for a quarter of a mile over a loose sandy soil and that before the lower end of the plat was satisfactorily irrigated, enough water had been applied to cover the entire tract to a depth of over 2 feet. It is certainly safe to predict that such methods of irrigation would ruin any soil. The results of the drainage system recently constructed in this part of the valley are given on page 34.

A Farmers' Bulletin of this Department [a] gives two instances of land, which, under favorable conditions, filled with ground water to such an extent that it had to be abandoned. One instance cited is in the Bear River Valley, Boxelder County, Utah, where the valley lands have varying slopes with the heaviest ones near the hills and the lightest near the river. The soils range from a sandy loam to a clay, and are very deep. The cuts of the Bear and Malade rivers are from 50 to 100 feet deep, and it was thought would afford excellent drainage, but in spite of the seemingly favorable conditions many of the lower lands were affected by the rise of ground water and alkali soon after the water was turned on. Another instance noted was in Emery County, Utah, where the soil is an alluvial sandy loam in which was found a layer of shale. This layer was sometimes found at or near the surface and sometimes several feet deep. Immediately below the shale, however, is an open, broken layer of about the same material which it was thought would afford excellent drainage, but within a few years after the beginning of irrigation wet spots and alkali began to appear and soon whole farms had to be abandoned.

It is the history of irrigated land that nearly all of it sooner or later fills with water and has to be drained. Numerous other cases could be named, but it is unnecessary. It is well known that the heavy clay soils of the Rio Grande Delta soon fill with ground water, and there are numerous instances where the lighter soils along the resaca banks have become filled and the alkali concentrated so that no vegetation whatever will grow. Especially is this true where the resacas are used as storage basins or where a large canal is maintained across this soil, a notable example being the Chicago Gardens, about 3½ miles northeast of Brownsville. In this locality the water stored in a resaca has seeped out along the porous stratum previously referred to, the land filled with ground water to within a few feet of the surface, and such a heavy crust of alkali formed that plants will not grow. Resacas should not be used for storage purposes unless adequate drainage is provided for the light soils bordering them. As has been previously explained, there is usually a layer of sand and silt extending from the resacas to, or nearly to, the heavy clay lands between them. This porous stratum will allow water to seep out under the land and form a water table that may in time cause a concentration of alkali. Especially is this true where levees are constructed along the banks and a head of water maintained in the resaca. Borings should be made to determine the nature of the soil before any depression is used as a reservoir. In some cases canals have been constructed across sandy soils, and in others the soil has been stripped, leaving only a sandy subsoil for the base of the canal. It was not learned that any attempts had been made to prevent the loss of water that is sure to follow such methods. Such a waste of water is not only a loss to the company pumping it, but it will fill the subsoil with water and hasten the necessity of drains.

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[a] U. S. Dept. Agr., Farmers' Bul. 371.

Even the lighter loam soils farther up the valley are liable to fill with water in time. It is frequently said that these soils are sandy and dry for a depth of 40 to 50 feet and will never fill up, but it is highly probable that they will. A type of this soil can be found near Mercedes where it has already filled up, and an alkali stain shows as much as 300 or 400 feet from the main canals. The water in wells near the canals has risen 5 or 6 feet in the last year, and in some cases now stands within 13 feet of the surface. The typical alkali stain is beginning to show in the low spots and highway ditches at a considerable distance from the canals, indicating that the water table is near the surface and that it has filled the soil either down to water or else to a layer of impervious clay. The north fork of the arroyo is now discharging a small but constant stream of water, whereas it was originally dry. In some places the seepage water may pass to this outlet far enough below the surface to prevent a concentration of the alkali, but it is probable that even in the most favored localities some drainage will be necessary, especially when the land is all brought under cultivation and irrigation. It is certain that drainage will be necessary for a large part of the land.

In this connection it may be said that the second lift lands are not immune. Near McAllen these lands are underlain with a heavy, highly impervious layer of clay, and the soil has already filled with ground water and a crust of alkali formed near the canals that contains water a large part of the time. In all the lighter soils seepage water will pass freely, and a large amount may be expected to and does pass into the ground. It is reported by reliable officials that in some cases their canals lose over 50 per cent of the water between the river and the farms. Add to this the excessive amount of irrigation water applied, and it is easily conceivable that even the deepest soils will fill up. Actual current meter measurement has shown that in some cases in the Pecos Valley over 2 feet of water have been applied in one irrigation, and in the lower Rio Grande Delta 10 inches per irrigation have been applied about every ten days. If the voids of the soil be assumed as 33 per cent, then 1 foot of water applied will fill up 3 feet of soil, and neglecting evaporation, 2 feet of water will fill 6 feet of soil. Considering all this, together with the fact that the average annual rainfall is 28 inches and the maximum 60 inches, it is safe to predict that a large percentage if not all of the lands in the lower

Rio Grande Valley will in time fill up with water to such an extent that drainage will be necessary. In the meantime seepage from canals should be stopped as far as possible, irrigation water should be used sparingly where the mineral content of the soil is well distributed, and ditches should be provided for any excess irrigation or rain water.

METHODS OF RECLAIMING SOILS.

A good many methods of freeing soils from injurious salts have been tried, but only a few of the most important will be mentioned here. Scraping the surface, the use of chemicals, flooding, and the drawing off of the water and flooding with underdrainage are the most frequently tried.

Scraping the surface may be of temporary benefit if the most of the alkali is concentrated at the surface, but since there is usually more or less distributed throughout a soil wherever a crust appears upon the surface, it is quite probable that the saline matter will again concentrate at the surface to the detriment of plant growth. This method is expensive, since besides the labor necessary it removes some of the most fertile soil, and therefore is not recommended.

The use of chemicals is sometimes desirable and even necessary, especially where the alkali consists of the sodium carbonate. This form of alkali breaks down the mechanical structure of the soil and makes it more or less impervious, so that it is extremely hard to wash out the saline matter. In this case calcium sulphate (gypsum) is sometimes added when a chemical reaction occurs, forming sodium sulphate and calcium carbonate. The sulphates, as stated heretofore, are the least harmful of the alkalis, and the calcium carbonate is harmless to plant growth. Not all analyses of soils, so far observed in this section of the State, contain an injurious amount of the harmful carbonates, so this method need not be considered further here.

Flooding and drawing off the water can not result in the permanent reclamation of land from alkali unless there be none except at the surface, which is very unusual. It is an aid, however, if the proper drainage is supplied, in that a large percentage of the salts concentrated at the surface may be directly removed and not forced down through the soil to be carried away by the underdrainage system. In an open sandy soil it might wash down quite readily, but in the heavy soils every precaution must be taken to keep as much alkali as possible out of the first 4 or 5 feet, since water will percolate through it but slowly, and hence remove the alkali slowly, no matter how close the drains may be laid. Flooding and drawing off the water dissolves some of the saline matter just at the surface, but does not remove it deep enough to prevent the action of evaporation from again drawing on the supply below and concentrating it at the surface.

Flooding and underdrainage has proven the most successful method yet tried. This method consists in laying tile or wooden drains underground and then constructing small levees to hold a head of water over the land sufficient to force a large amount of water downward through the interstices of the soil. This water will dissolve and carry out with it a certain amount of the salt present, and if enough water can be forced through, the soluble salts can in time be leached out. In this method of reclamation it is desirable to put the drains deep enough to hold the water table down 4½ or 5 feet below the surface in order that evaporation may not draw readily from it. It has been found by the engineers of this Office that when the water table is held down 4½ or 5 feet below the surface evaporation takes place very slowly, and that under all ordinary circumstances the judicious use of irrigation water and a reasonable amount of cultivation will prevent any serious rise of the alkali. As previously stated, if more water is put downward through the soil than is allowed to come up through it by evaporation, there need be no fear of alkali concentrating in harmful quantities. The length of time required to free a soil from alkali depends entirely upon the amount of saline matter present, and the rapidity of the passage of water through the ground depends upon the porosity of the soil and the distance to a free outlet. If the soil be open and drains constructed close together the alkali may be removed by flooding for a few months or even weeks, but if it be a close clay soil it may require a year or two. If the soil is heavy and close the water should be frequently drawn off and the surface plowed deeply. Subsoiling is practiced in some localities with good results.

RESULTS OF ATTEMPTED RECLAMATION.

ATTEMPTS IN THE LOWER RIO GRANDE VALLEY.

Several more or less successful attempts have been made to reclaim the lands upon which rice was grown until the concentration of alkali caused its abandonment. The last rice grown by the Brownsville Land and Irrigation Company was the fourth crop planted on a small tract of land about 6 miles northwest of Brownsville, that had previously been ditched and flooded. Ditches were constructed about 3 feet deep and 300 to 400 feet apart and the land washed for several weeks before the rice was planted. The soil was of the medium type and the outlet clear, so the water could move readily along the ditches. The growing crop was kept well flooded and considerably more rice was raised than the previous year. It was estimated that 65 per cent of an average crop was raised, whereas the year before only about 30 per cent was raised. This land was then sold and planted to cotton and general crops that yielded quite well for two years, but the ditches were allowed to fill with growing weeds and silt until the land has now again become badly alkalied. If the ditches had been deeper and well maintained, the improvement would probably have been permanent, or had the shallow ditches been properly cared for and the land well cultivated and heavily irrigated a few times in the spring good crops could probably have been grown every year.

An instance of the gradual reclamation of a field without ditches was noticed near Olmito. The land is of the light type and was cropped in cotton by ordinary irrigation and cultivation. The third crop was growing on the land and the owner remarked that it looked better than either of those previously grown. An examination of the conditions showed that the most of the tract was somewhat higher than the surrounding farms and was underlain with a silty sandy subsoil. A depression on the east end of the farm where the soil was heavy was entirely unproductive, and the farm to the north lying somewhat lower and with a slightly heavier soil had been abandoned. Inquiry brought out the fact that this farm had gradually decreased as the other increased in productivity. It is highly probable that the alkali was carried to the depression and the other farm by irrigation water moving through the soil, leaching it out of one tract and depositing it in the others.

Perhaps the most recent reclamation work to be successfully carried out was the drainage and washing of a small garden by F. W. Rusteberg, at the Chicago Gardens, about 3½ miles northeast of Brownsville. The tract in question consists of two lots each 160 by about 250 feet, lying along the bank of a resaca that is used as a storage reservoir. The land surface is only from 3 to 5 feet above the water level in the resaca, and had become so badly alkalied that seeds would not germinate or plants grow. The high stage of water in the resaca had forced water into the porous substratum that is found here, and, in fact, along nearly all of the resacas, forming a water table near enough to the surface for evaporation to concentrate the alkali. It was desired to wash the alkali from the soil sufficiently to allow the plat to be used for a seed bed. Accordingly, 4 parallel drains were laid out at right angles to the resaca, and 80 feet apart. They were to be constructed of 4-inch tile laid 5 feet deep, but as tile were not obtainable at the time and it was necessary that the land be ready within a short time, open ditches were dug from 4 to 4½ feet deep. Checks were then laid out about 15 by 25 feet in dimension and the levees constructed so the land could be flooded to a depth of 10 or 12 inches. Water was pumped from the resaca by a motor windmill with a 12-foot wheel, fitted with an 8-inch direct-stroke cylinder and a 4-inch rotary pump. The total lift was about 6 feet, and the pump ran about 12 hours per day. As both the time and water supply were limited it was decided to wash but one plat (80 by 200 feet). When the water was applied it passed through the ground and was carried off by the ditches so rapidly that it was impossible to keep the entire plat covered, so the supply was confined to a few of the small checks in order that a head of from 3 to 10 inches could be maintained. Mr. Rusteberg estimates that water was maintained from 3 to 10 inches on each check for 12 hours each day for seven days. The land was then allowed to dry, after which it was plowed and the seed planted. The seed germinated and the plants grew as well as before the rise of the alkali, except on one check, where the soil was somewhat heavier than the remainder and where it is also possible that less water was applied. The soil is a light silty clay loam locally known as resaca land, and the rapidity with which the alkali was washed out is no doubt due to its open porous structure.

RECLAMATION IN THE PECOS VALLEY.

There are two principal types of soil in the Pecos Valley so far as texture, and hence drainage, is concerned; one a sandy loam with a substratum of sand and gravel and an occasional gypsum ridge, and the other a medium heavy clay with a clay subsoil. The outlet ditches were constructed from 5 to 7 feet deep, and although they have been completed but a short time the results so far obtained indicate positively that they will be a remarkable success, especially for the lighter soil. The sand or gravel layer occurs at a depth of 5 to 7 feet in the swales and is a natural passageway for the ground water. A careful examination of the ditches shows that in most places the water-bearing layer is even with or slightly above the ordinary seepage water-flow line, and that the water enters the ditch very readily. In some few places where this layer is below the ditch the water bubbles up from the bottom and in others it moves around the obstructions and into the ditch at some other point. Even in case of the gypsum ridges the water is not held up but passes under or around the obstruction. The water table has been lowered from 3½ to 6 feet in all the lighter soils, as much as a mile from the nearest ditch. The land has nearly all been irrigated and while in some cases the water in wells raised a foot or so it subsided in a short time, showing that under ordinary conditions it can be expected to remain down where it will cause no injury. Land that was covered with a crust of salt and that was too marshy even for grazing purposes has been dried out so it is as firm as any in the valley and the salt crust has nearly disappeared. But little has been done toward washing the alkali from the soil, but no serious difficulty should be encountered on the sandy land. The heavy soils can not be reclaimed so readily and lateral ditches will be necessary, but the fact that all surface water has disappeared and that the marshes are dry and firm shows that the water will pass through the soil and that it can be freed from the alkali if properly handled.

RECLAMATION IN THE WESTERN STATES.

Two recent publications by the Office of Experiment Stations[a] describe in detail the methods used, results obtained, and cost in the drainage of irrigated lands in the West in 10 experiments in Utah and two in the San Joaquin Valley, California. The former deals mostly with light pervious soils with a good slope, affected usually by seepage water from a high-line canal or higher lying irrigated lands, and the methods used were usually a combination of the intercepting and relief systems of drainage. In nearly all cases it was found that an intercepting ditch, laid at an angle of from 45° to 90° with the slope, proved satisfactory in collecting the most of the seepage flow and that the remainder should be cared for by lines directly down the slope. The latter bulletin deals with a sandy soil underlain with waves of impervious hardpan, and with a slope of about 5 feet per mile. The laterals were laid out parallel and from 200 to 480 feet apart. The land was so level that it was necessary to pump the drainage water or else construct an outlet ditch some 20 miles to where a gravity outlet could be obtained. The former method was used for the experiment. The method of blasting the hardpan, laying out the checks, and of washing the soil is described. A bulletin of the Bureau of Soils[b] gives general results of several experiments in reclaiming alkali lands.

RECLAMATION IN EGYPT.

In a bulletin of the Bureau of Soils[c] Thomas H. Means gives his observations on the reclamation of alkali lands in Egypt, and according to his report the lateral drains are usually open ditches about 30 inches deep and from 150 to 450 feet apart. After the ditches are constructed small levees are thrown up, so that the land can be flooded to a depth of 4 inches. Water is then turned on and maintained at that depth until time to plant a crop or until the water supply gets too short to be used for that purpose. A salt-resistant crop is planted the first and second years and the third year the land is usually quite free of mineral salts. The soil is a heavy, silty clay that has been deposited by overflows of the River Nile, the depth of this deposit usually varying from 1 to 6 or 8 feet, and is underlain by sand or gravel. No statement is made concerning the permanence of the improvement, but if the ground water stands at the level of the bottom of the ditches it is quite probable that evaporation will gradually concentrate the salt again so that periodic washing will be necessary.

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[a] U. S. Dept. Agr., Farmers' Bul. 371; U. S. Dept. Agr., Office of Experiment Stations Bul. 217.

[b] U. S. Dept. Agr., Bur. Soils Bul. 34.

[c] U. S. Dept. Agr., Bur. Soils Bul. 21.

PLANS FOR DRAINAGE.

In planning a drainage system the first matter to settle is the question of an outlet. Where an outlet can be secured into the Arroyo Colorado or the drainage ditches now under construction near Brownsville, the land can be readily drained by gravity, but in most of the upper part of the valley, especially on the second-lift land, drainage water will have to be pumped or else a system of outlet ditches provided.

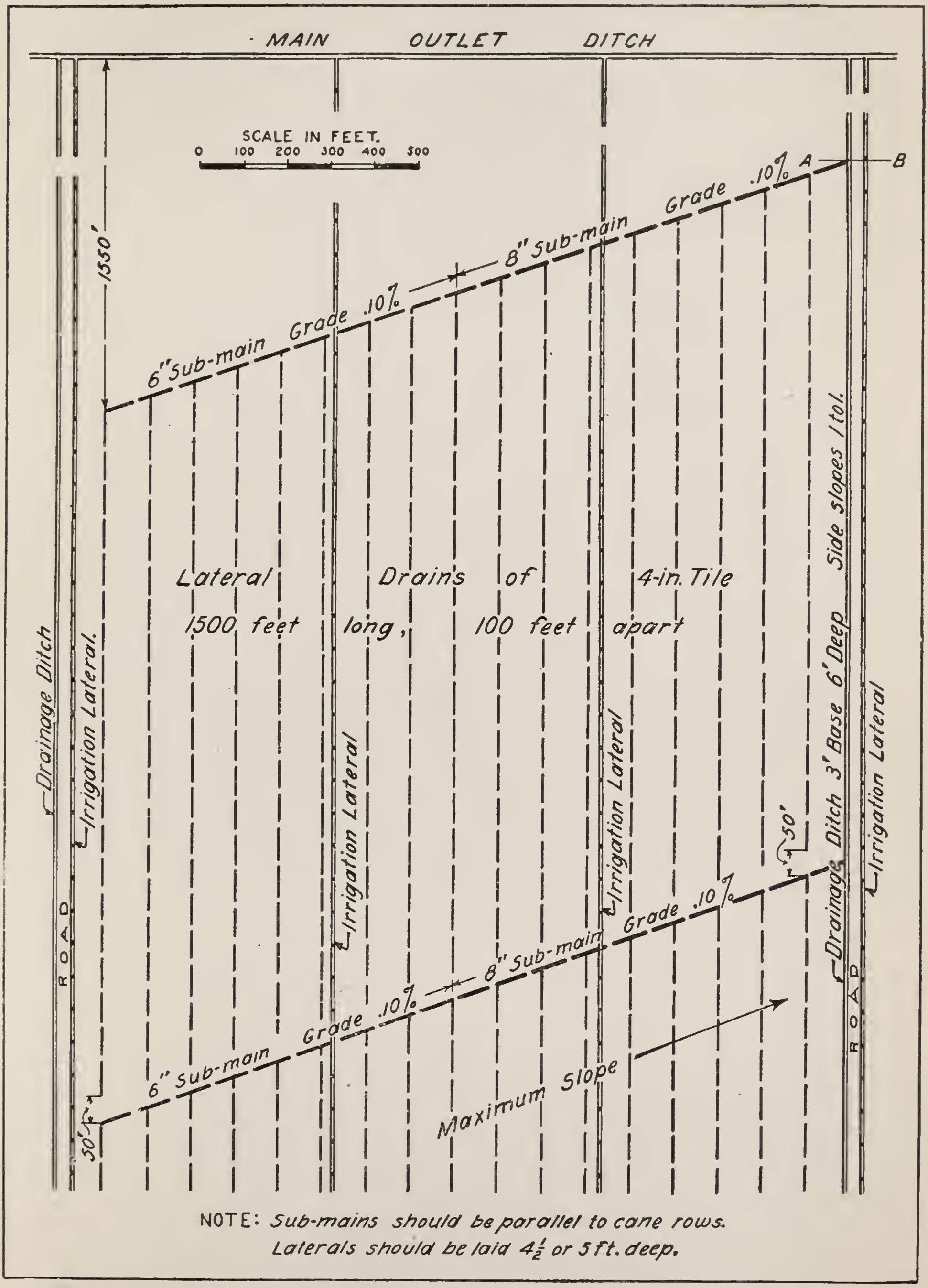
A careful examination of the soil and subsoil should always be made before any extensive drainage work is undertaken, especially if it is desired to cut off seepage water. The source and nature of the trouble should first be located. This can usually be accomplished by test pits or auger borings. If the soil has become filled by irrigation and rain water until it stands close enough to the surface to injure the roots of plants or cause the alkali to concentrate at the surface, the best remedy is to construct deep ditches in such a manner that the water table will be lowered. If, however, the trouble is only in spots it is probably due to seepage water from a canal or from lands of a higher elevation. If it develops that seepage is the cause of the rise of ground water, its source should be located and the direction, depth, and slope of the water-carrying stratum determined. Deep ditches should then be cut into it in such a manner that a water table will not form within 5 feet of the surface. An intercepting ditch may answer the purpose if it has sufficient fall. If the slope of the intercepting ditch is slight and that of the water-carrying stratum great, so that there is less resistance to the passage of the water through the soil than along the ditch, it will not cut off the water. In such a case the ditch should be constructed more nearly in the direction of flow and a drain should be constructed within 100 feet of the upper line of the seep spot. The effect of this line may be noticeable for a distance of from 200 to 2,000 feet below, depending on the porosity and depth of the subsoil and the head of the water.

If it is desired to wash a soil containing excessive alkali, the drains should be parallel and run approximately with the slope, the distance between drains depending entirely upon the soil in which they are laid. In close, heavy clays it may be necessary to construct them as close as 50 feet and in open sandy soils 300 or 400 feet may be close enough. The depth at which they should be laid depends upon the depth reached by roots of plants, the capillary action of water, and the porosity of the soil. Grass and truck crops will thrive with a water table within 3 or 3½ feet of the surface, provided there is no alkali present, but alfalfa and some fruits require a greater root space. The depth that will prevent any considerable evaporation is usually considered safe, and it is recommended that all lateral drains be constructed that deep where possible. If the soil be a dense heavy clay that water will not penetrate readily, it may be necessary to put them shallower and close together and wash the soil as often as alkali concentrates in injurious amounts. As tile are laid shallower the lines should usually be laid closer. The water table is not usually a plane surface, as might be supposed, but is a curve with its ends in the lines of tile and its highest point midway between the lines. The closer the structure of the soil and subsoil the steeper the curve. This is due to the resistance of the passage of the water. The only force that causes ground water to seek a ditch is the action of gravity. If the soil be open and porous, water will move through it freely and the curve will settle down in the soil until it may become nearly, if not quite, a straight line; but if the soil be close and heavy the curve will be steep, and if the lines are too far apart the ground water may remain close enough to the surface between them to injure plant growth or allow a concentration of alkali.

All lateral drains should be constructed of tile when possible. It is not only cheaper to lay tile than to make an open ditch but it saves the land, keeps out weeds, farms easier, and appears better. An open ditch 5 feet deep in the ordinary soil will be about 12 feet wide at the surface of the ground, and cost about $2.75 per rod, while a rod of 6-inch tile laid to the same depth will cost but about half that amount. In addition to the first cost of an open ditch there will be a small cost for maintenance each year, while tile properly laid will require no attention for years.

For the drainage of the heavy clay soil it is thought best to lay the lines of tile parallel and at a distance of about 100 feet apart and about 5 feet deep. Different conditions will require different widths and depths, and they must be decided upon in the field. Figure 3 shows the plan outlined for the underdrainage of a part of the Ohio and Texas Sugar Company's plantation. This land has a high salt content and it is desired to lay the tile at the most economical distances apart and depths to effect reclamation. The soil is very tenacious and heavy and the water will pass through it but slowly, but it is thought that enough will pass through into the tiles to overcome the effect of evaporation and change the direction of the movement of the salt, and that in time it can be freed from the salt sufficiently for the growth of ordinary crops.

In general, the drainage of the Lower Rio Grande Valley lands can best be accomplished by parallel lines of tile with or nearly with the slope, together with an intercepting ditch along the upper side of the affected tract if the water comes from a canal or higher lying irrigated lands. Where the seep spot is small and a gravity outlet is not available it will be necessary to pump the drainage water. This



NOTE: *Sub-mains should be parallel to cane rows.*
Laterals should be laid 4½ or 5 ft. deep.

FIG. 3.—Plan of underdrainage of a part of the Ohio and Texas Sugar Company's plantation.

method will probably be necessary until enough land has been swamped to force the construction of expensive outlet ditches. These outlet ditches will be necessary after a time and should be constructed as soon as districts can be organized.

The cost of drainage works varies so greatly that any estimate without a careful examination or survey is but an approximation. Outlet ditches will probably cost between $2 and $15 per acre, and lateral drainage between $7.50 and $35 per acre. The cost of construction of lateral drains in the heavy clay soils where they must be laid close together will no doubt reach the higher figure in many cases, while in the porous loam soils it may not exceed the lower figure. The installation of such a system as shown in figure 3, including the lateral open ditches, will cost about $30 per acre.

SUMMARY.

(1) There is not an excessive amount of alkali in the most of the lower Rio Grande Valley soils if it is kept distributed, but if allowed to become concentrated by seepage and evaporation there is sufficient in nearly all of the soils to prevent plant growth.

(2) The usual methods of irrigation farming tend to concentrate the alkali at the surface. When the soil becomes filled with ground water to within 3 or 4 feet of the surface, alkali is concentrated very rapidly. In general, the allowable alkali content for a heavy clay soil is less than for a sandy one.

(3) The Rio Grande water is a good irrigation water. Any large amount of alkali concentrated by its use will necessarily come from the soil.

(4) It is very probable that in time the soils of the lower Rio Grande Valley will fill up with ground water near enough to the surface to cause the alkali to concentrate in harmful quantities, and that extensive drainage works will be required.

(5) Any soil that is porous enough to allow the ready passage of water can be reclaimed. Sandy or loam soils can be reclaimed cheaper than heavy clay soils.

(6) In general, the lateral drains should be made of parallel lines of tile, running down the maximum slope, with perhaps an intercepting line if the soil is porous and the water comes from a canal. It should be remembered that an intercepting ditch must be laid to such a grade that there is less resistance to the flow of water in it than through the soil in the direction of the maximum slope.

(7) It should be borne in mind that thorough drainage does not mean a ditch 1 or 2 feet deep choked with weeds and débris, but that it means outlet ditches 6 to 7 feet deep with laterals 4½ to 5 feet deep, and at such distance apart that they will remove the water from the soil faster than it is drawn up by evaporation.

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